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RECTIFYING SYSTEMS FOR AERIAL PHOTOGRAPHS

SECTION 1 - INTRODUCTION

In this report the problems of image rectification are outlined and a number of systems are detailed. Based on these discussions an approach is outlined which will provide an immediate solution to the rectification problem for the Perkin-Elmer Model 501 Panoramic Camera and a plan is submitted which will lead to a more general solution to the rectification problem.

SECTION 2 - GENERAL

Aerial photographic techniques are in constant use by the military to obtain intelligence and data for map-making purposes. Since these photographs are taken from an airborne vehicle which does not provide a stable platform for the cameras, interpretation and accurate distance measurements are extremely difficult requiring complex procedures and processes.

The geometric differences between a vertical aerial photograph and a map can be mathematically taken into account so as to produce accurate data. The task becomes considerably more difficult with photographs in which the camera axis has been tilted away from the true vertical. The procedure by which an aerial photograph having tilt is converted into one with no tilt is termed "rectification". True rectification preserves the characteristic that a photograph is a simple central point perspective projection and thus permits the employment of precision photogrammetric mapping practices.

Nearly all aerial photographs which have been taken with conventional and panoramic type aerial cameras have the camera axis tilted away from true vertical. The roll and pitch of the aircraft on a photographic mission is mainly responsible for tilted photographic data. In the case of oblique photographs, the optical axis of the camera has been deliberately tilted away from vertical. The rectification problem in both these instances is essentially the same, differing only in the magnitude of correction to be made.

A map is defined as an orthogonal view in which every incremental detail is shown as though it is viewed from vertically above. With this definition in mind we can further establish differences between a true map presentation and a vertical photograph or a rectified tilted photograph.

Since aerial photographs are perspectives, variations in elevation appear as displacements in a true datum plane. The major contributing factors to this form of mapping error are the actual variations in elevation of the earth's terrain and the earth's curvature. The latter factor becomes very significant in photographs taken at high altitudes with wide field angle camera systems. Vertical and rectified photographs readily lend themselves to automatic correction for earth's curvature, while the effects due to the terrain's variations in elevation could only be partially corrected by the use of complex mathematical computer. To achieve automation in the correcting process, it will be necessary to have elevation data from previous surveys or to automatically compute the elevation correction factors from the perspective components of the aerial photographs.

Although it is desirable to perform all the corrections with one device, the scope of the task dictates a less ambitious program. An equally satisfactory approach is one in which the device is capable of performing the prime objective of rectification with provisions for the addition of refinements in the correction process deferred for the future. The latter approach is recommended here. The problem of rectifying tilted photographs being the first task to be followed at a later date with modifications to include correcting for earth's curvature and variations in terrain elevation in that order.

The rectification schemes in use today employ either optical, graphic, or analytical procedures. The latter two methods although accurate are tedious point by point analysis even with the aid of mechanical and electronic computing devices. Optical methods permit rapid and accurate rectification of photographs with small tilt angles. However, precision rectification of high obliques by optical means requires large complex equipment and elaborate procedures which perform the rectification in parts or stages. To insure that geometric properties are accurately preserved with an optical rectifying system, it is necessary to know the focal length of the cambra, the focal length of the rectifying lens system, the tilt angle and the ratio of scale change desired. Although the procedures and equipments used in optical rectification systems appear to be complex, they do permit rapid and accurate rectification of tilted aerial photographs. To gain greater flexibility electronic rectifiers have been proposed. In general the use of electronics for rectification purposes should permit greater flexibility in correcting aerial photographs for more factors and with greater limits. These gains will probably be purchased at the expense of a loss in resolution, longer processing time and an increase in equipment complexity. An additional advantage of an electronic or opto-electrical rectifier would be in the control of grey scale so as to enhance detail in bright and dark areas of the original aerial photographs.

Before engaging in a discussion of various rectification schemes, some fundamentals relationships must be established which will illustrate the differences between a conventional type of aerial photographic camera and a panoramic type camera. It is these factors which complicate the rectification process.

A photograph taken with the conventional aerial camera held truly vertical over flat terrain for small field angles would give map positions directly. Here the distance of a point from the nadir on the photograph to that on the terrain is related by the ratio of focal length to altitude of camera. It is also interesting to note that the heading from the nadir to a point is exact. The radial distance from the nadir to the point need only be corrected for earth's curvature.

Conventional aerial ~~photographic~~ cameras used today are designed for diagonal field coverage of from 20 to 90 degrees, while panoramic cameras are designed to photograph strips 40 to 45 degrees in width in the direction of line of flight and up to 180 degrees at right angles or transverse to the line of flight. Conventional cameras employ a shutter and the stationary lens system, while panoramic cameras scanning operation is performed by a moving optical element, moving slit, moving film or a combination of these functions. The scan is performed at a constant angular rate transverse to the line of flight. The relationship of the scale ratio given for conventional photographic cameras does not hold for the panoramic except for points in a line which passes through the nadir point and in the direction of line of flight. The geometric relationship which expresses the scale factor is given by

$$\frac{d'}{d} = \frac{f}{H}\left(\sqrt{\frac{\phi + \tan^2\alpha}{\sin^2\phi + \tan^2\alpha}}\right)\cos\phi$$

where d' = distance from nadir to point on photograph

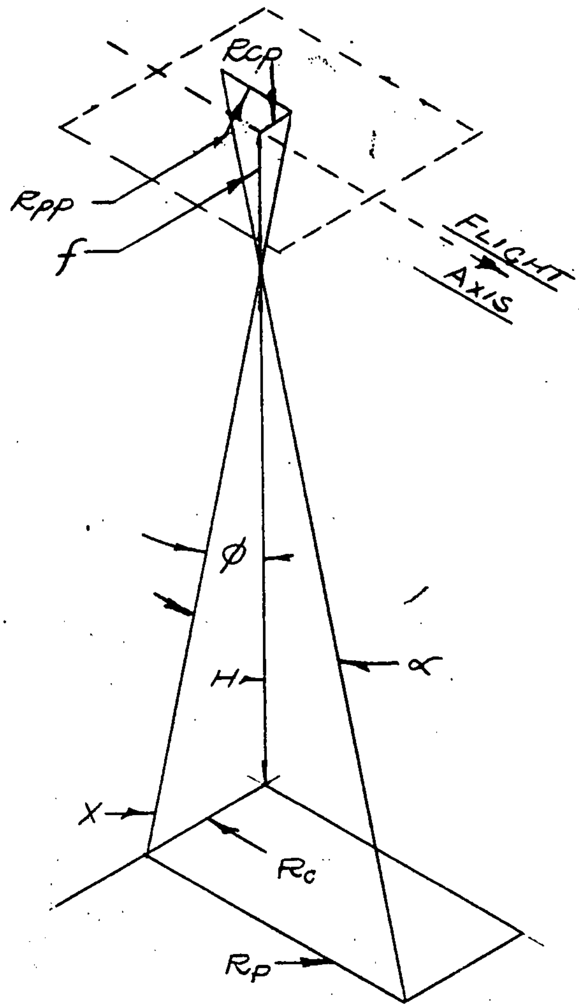
d = distance from nadir to point on terrain

ϕ = scan angle transverse from optical axis

α = oblique angle from the transverse scan axis to the point (See Figure II).

The differences between the conventional type and panoramic aerial cameras clearly indicate that the rectification procedure would be quite different in each case.

The geometric analysis of photographs is based on the premise that the area photographed lies in a plane tangent to the sphere at the nadir point and that all points on the surface of the sphere appear in the plane as a perspective projection with the center at the lens nodal point. Figures 1 and 2 illustrate the mathematical relationships under level flight conditions for the conventional and panoramic cameras respectively.



ROLL = 0   PITCH = 0

$$X = \frac{H}{\cos\phi}$$

$$X' = \frac{f}{\cos\phi}$$

$$\tan\phi = \frac{R_C}{H} = \frac{R_{CP}}{f}$$

$$\frac{R_{CP}}{R_C} = \frac{f}{H}$$

$$\tan\alpha = \frac{R_P}{X} = \frac{R_{PP}}{X'}$$

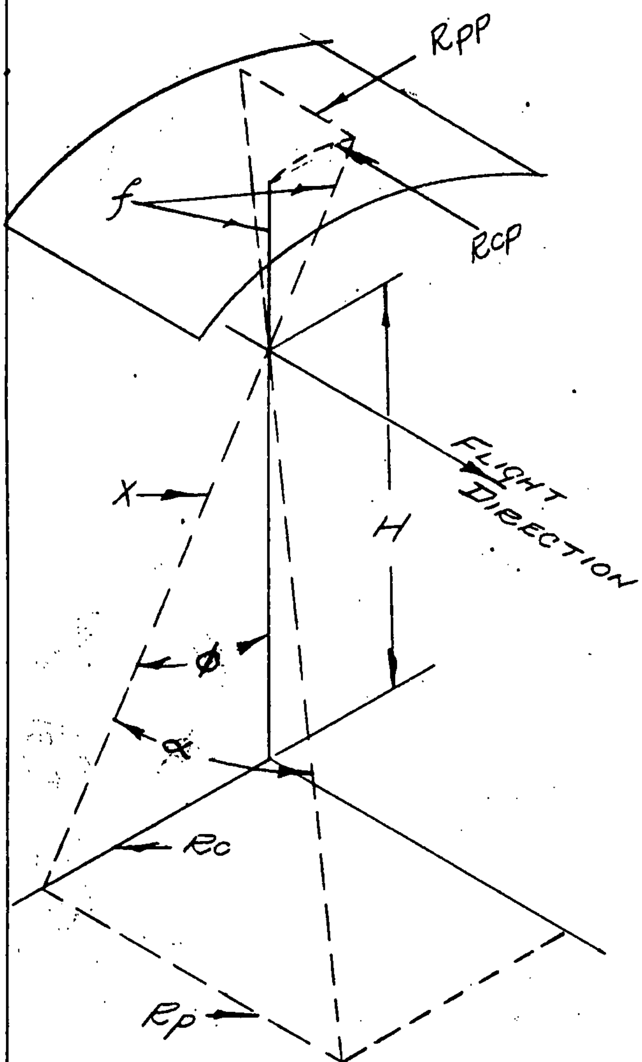
$$= \frac{R_P}{H/\cos\phi} = \frac{R_{PP}}{f/\cos\phi}$$

$$= \frac{R_{PP}}{R_P} = \frac{f}{H}$$

CONVENTIONAL TYPE CAMERA
R_P & R_C COMPONENTS IN LEVEL FLIGHT.

FIG I.

ROLL = 0 PITCH = 0



RATIO OF COMPONENTS PARALLEL TO FLIGHT DIRECTION

$$\tan\alpha = \frac{R_P}{X} = \frac{R_{PP}}{f}$$

$$X = \frac{H}{\cos\phi}$$

$$\frac{R_{PP}}{R_P} = \frac{f}{H}\cos\phi$$

RATIO OF COMPONENTS ACROSS FLIGHT DIRECTION

$$R_{CP} = \phi f$$

$$R_C = H\tan\phi$$

$$\frac{R_{CP}}{R_C} = \frac{f}{H}\left(\frac{\phi}{\tan\phi}\right)$$

PANORAMIC TYPE CAMERA
RC & RP COMPONENTS IN LEVEL FLIGHT

FIG II.

For the conventional type aerial camera we note that the components of a point from the nadir transverse to the line of flight (R_c) is related to the corresponding component on the negative (R_{cp}) by the ratio of H/f where H is the altitude of the camera and f is the focal length of the taking lens. The components R_p and R_{pp} parallel to flight axis are related by the same ratio H/f.

For the panoramic type of camera the relationship for cross and parallel components differs considerably from the conventional case since the film platen is effectively cylindrical and the transverse scanning prism has a constant angular rate. Here the datum plane component from the nadir to the scanning line is related to the cross-component on the negative geometrically by $\frac{R_{cp}}{R_c} = \frac{f}{H}\left(\frac{\phi}{\tan\phi}\right)$ where ϕ is the scan angle expressed in radians, and the components in direction parallel to flight line are given by

$$\frac{R_{pp}}{R_p} = \frac{f}{H}\cos\phi$$

In summary we note that for the conventional camera the transverse and parallel components are related by the simple ratio of focal length to altitude, while for the panoramic type camera the f/H ratio is modified by a trigonometric functions. These relationships must be further expanded to include roll and pitch to establish complete computer requirements. Applicable mathematical derivations are included with specific systems described in the appendix. The simplified relationships developed here illustrate the differences between conventional and panoramic cameras.

The effect of roll and pitch is illustrated in a simplified manner in Figure III. Here a scan slit which is parallel to the aircraft heading is projected onto the datum plane and its deviation from the projected ground path of the aircraft is established as a function of transverse scan angle, roll and pitch. It is found to be

$$s = \tan^{-1}\left(\sin p \left[\tan(\phi + r)\right]\right)$$

where s = Scan line deviation angle from normal

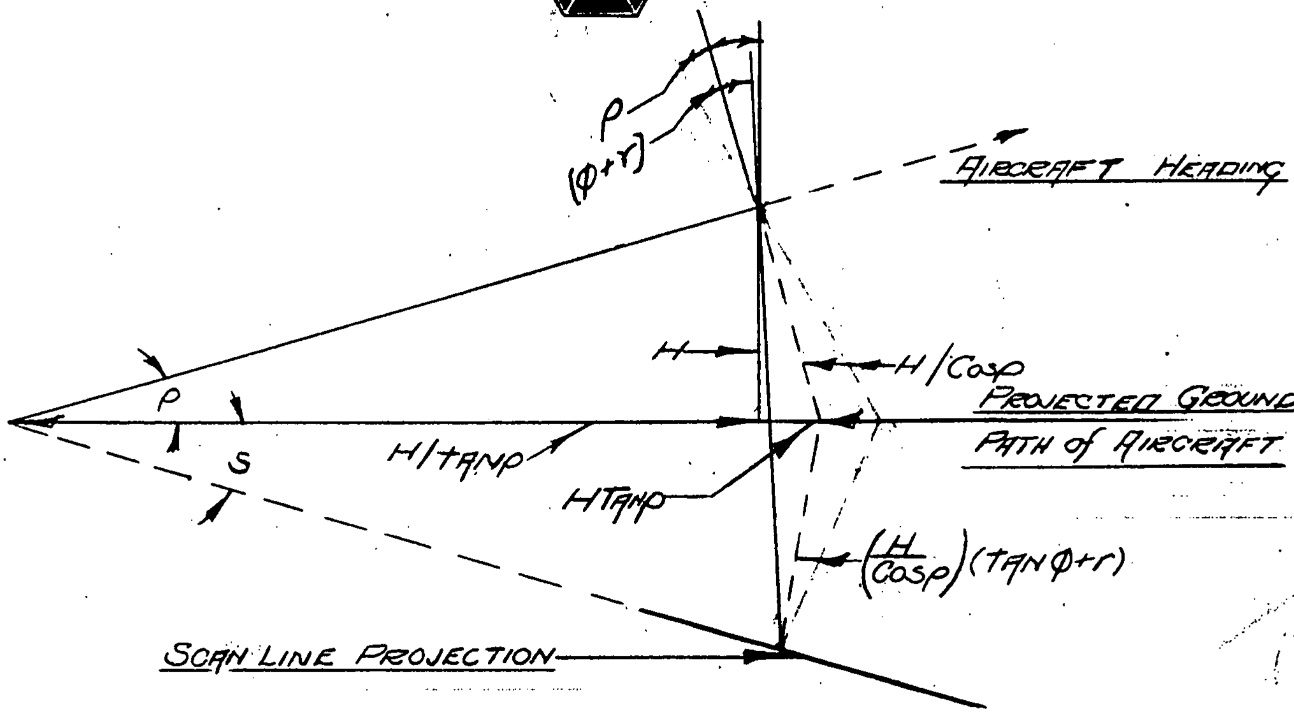
p = pitch angle

r = roll angle

d = transverse scan angle

For example, s equals approximately 7° for a pitch angle of 4° and a scan plus roll angle of 60°. Clearly indicating the need for considering even small angles of roll and pitch. In addition, Figure III graphically illustrates that a line scanning rectification system requires that either the read-out or recording device be capable of rapid positioning in two demensions.

In the following section a number of rectification systems will be described and compared. Technical details of these rectification systems and the panoramic camera will be described in the appendix.



ROLL ANGLE = r

PITCH ANGLE = ρ

TRANSVERSE SCAN ANGLE = φ

$$S = \operatorname{Tan}^{-1} \frac{[H/\cos\rho]\,[\tan(\phi+r)]}{\frac{H}{\tan\rho} + H\tan\rho}$$

$$= \operatorname{Tan}^{-1} \frac{\tan\rho\,[\tan(\phi+r)]}{\cos\rho\,(1+\tan^2\rho)}$$

$$= \operatorname{Tan}^{-1} \frac{\sin\rho\,[\tan(\phi+r)]}{\cos^2\rho\,(\sec^2\rho)}$$

$$= \operatorname{Tan}^{-1} \sin\rho\,[\tan(\phi+r)]$$

EFFECT OF ROLL & PITCH ON SCAN SLIT PROJECTION

FIG III

SECTION 3 - TECHNICAL DISCUSSION

We have established some fundamental mathematical relationships which must be preserved in all the rectification schemes to be considered. Several systems by which rectification can be achieved will be described and evaluated. These will be followed by a method in which the rectified photograph can be further corrected for earth's curvature.

Rectification schemes can be subdivided into three categories: In the first group we could include devices which would rectify the entire photograph in one operation. Optical systems fall into this category. In the second group we would find schemes which employ a point-by-point analysis. Here, the picture elements are time-coded and then re-positioned by computation to form the rectified photographs; flying spot scanners employ these techniques. The third group would include schemes that are combinations of the first two groups, being devised of features from each group in a manner to permit satisfactory photographic rectification with a compromise in the best features of the two major categories.

Schemes in the first category which rectify photographs in their entirety, have these characteristics: The rectification process is completed in a relatively short time interval. They are capable of good resolution and the rectification can be checked prior to printing the result. Flexibility in usage is limited by scale change desired, field size, correction limits and type of photographic equipment.

Point-by-point automatic plotting techniques can be designed to be very exact and versatile at the expense of computer complexity. In these devices the scanning spot size is established by minimum resolution requirements. The original photograph is then scanned, processed through a computer and the rectified photograph is printed on a point-by-point sequence basis. Schemes falling into this category would employ optical, mechanical, and electronic procedures. These devices can be very versatile, permitting rectification over wide limits, scale change, and be independent of the original optical photographic system. This flexibility is, however, attained at the expense of complexity and rate of processing time. With careful planning the design of this type of equipment can be done in stages. The scanning and printing systems must first be designed and developed with the required degrees of freedom. The computer which schematically appears between the scanner and printer can be developed to perform one function with additional operations added at a later date.

In the third group would be included schemes which apply techniques between the two extremes of point by point plotting and corrections on an entirety basis. In this category would be included devices which would speed up the point by point plotting technique and simplify the geometric computations. Point by point plotting can be speeded up by scanning in increments or sections. By not exceeding the permissible error the same correction can be applied to several adjacent elements thus permiting the scanning of the area at a faster rate then possible with individual picture elements. In addition, optical mechanical techniques applied in the scanning and printing processes can perform scale and/or geometric computations thus simplifying the computer. Employment of these techniques will result in equipments which will perform the rectification process with additional compromises in accuracy and flexibility, in a shorter time than the point by point methods but slower than with optical processes.

In the following sections various schemes will be briefly described and compared. Design details and analyses for some of these are to be found in the appendix.

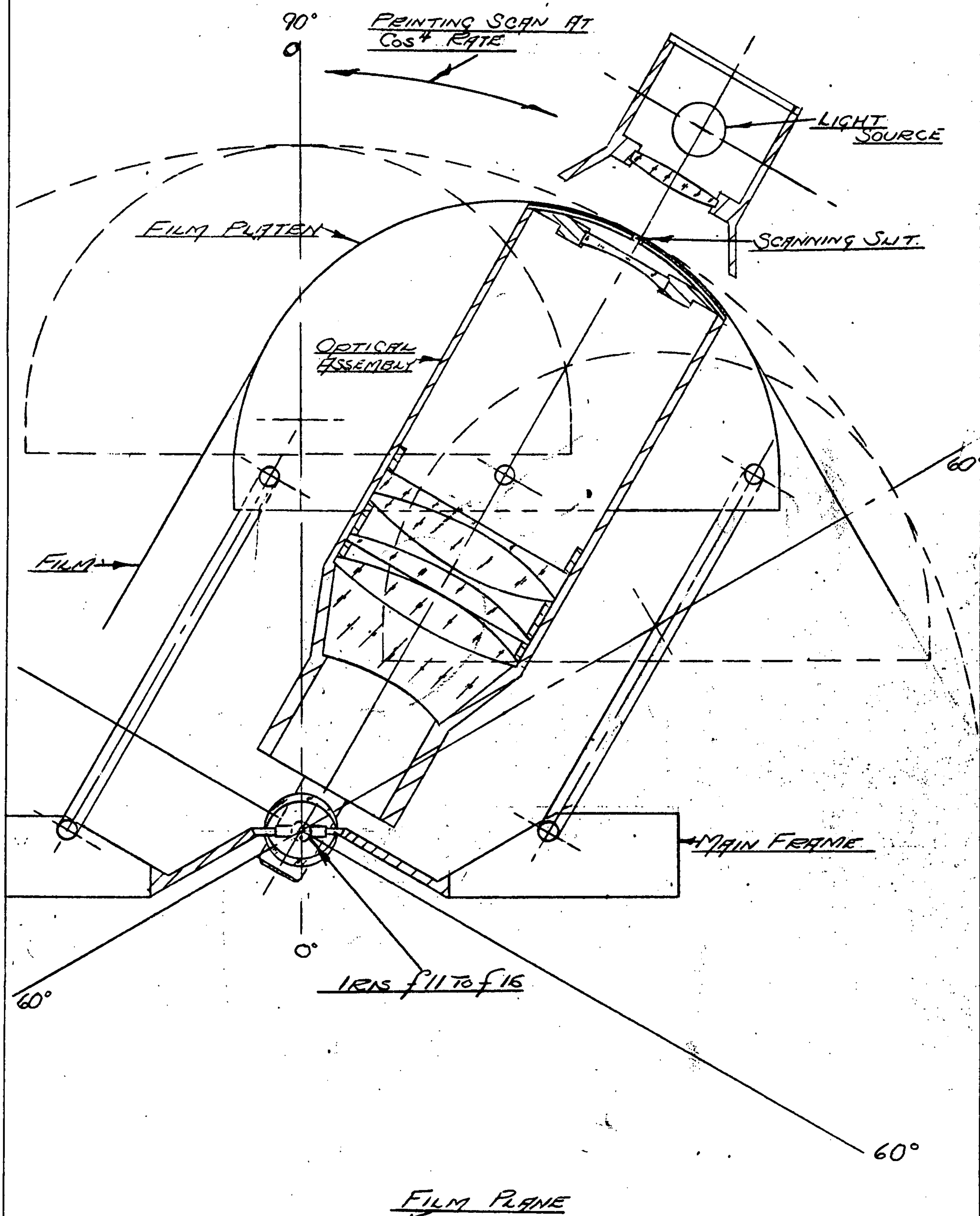
A. Optical Rectifier System

Since a number of accurate and reliable optical rectifiers are available for conventional type of aerial cameras, the techniques employed in these systems will not be described here. However, rectifiers for panoramic type cameras such as the Perkin-Elmer Model 501 are not available and therefore are included in this analysis.

The Panoramic Optical Rectifier has been designed to rectify data directly from 70mm negatives containing data recorded with a panoramic camera having a 3-inch objective focal length. The magnification is 1 to 1 at the center of the picture. The device is capable of rectifying images in a field angle of 41° parallel to the line of flight, and 60° transverse to the line of flight on either side of the vertical. With this device it is possible to correct for all angles of roll and angles in pitch of ±10°.

Figure No. IV illustrates in simplified form the mechanism in an optical rectifying system for panoramic type camera data. The optical system consists of an iris which is located at the 120° lens assembly, an objective lens, a slit with field flattener lens, a light source and collecting lens unit. A cylindrical film platen is ued to position the negative at the proper optical position. The light source, slit, field flattener and objective lens are mounted on an arm which pivots about the optical center of the 120° lens assembly. Movement of this assembly in an arc permits exposure of the negative to the illuminated slit at a pre-determined rate. The illuminated slit image is then projected into the film plane through the 120° lens resulting in a rectified photograph.

Corrections for roll and pitch are in quadrature about the 120° lens geometrical center. To compensate for these the 120° lens and the printing plane are rotated as a unit about the geometric center of the 120° lens assembly.



PANORAMIC DATA OPTICAL RECTIFIER

FIG IV

Although this optical rectifier is suitable for use with the model 501 panoramic camera it can not be used with conventional type aerial cameras unless extensively modified. It does, however, provide a compact, simple unit to perform accurate and rapid rectification of panoramic photographic data.

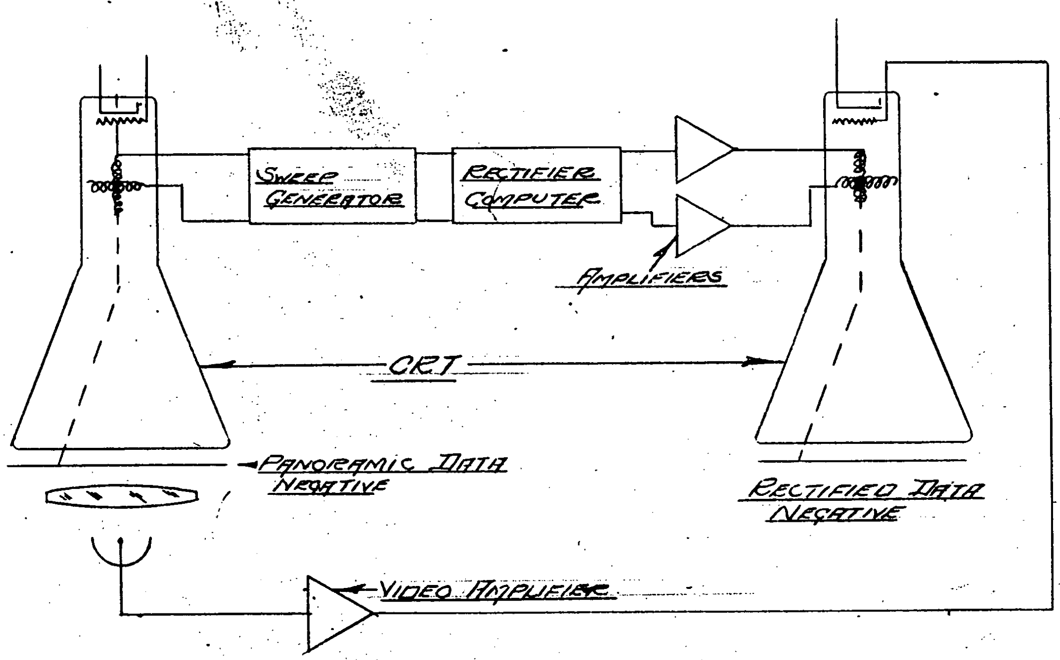
B. Image Converter Type of Rectifier

An interesting rectification scheme is suggested by the image converter tubes which are used in Snooperscopes. These devices are used to convert optical images in the near infrared to the visible. Resolution in the order of 30 lines/mm has been achieved with these tubes. For use here the converter tubes would have to be slightly modified. The conversion would be from a visible image to a visible rectified image requiring a changein photo cathode material. The rectification could be achieved by the insertion of electrostatic plates or an electromagnetic field so as to permit shaping of the elece tronic image in accordance with the rectification requirement.

In summary, the resolution of these devices is quite good. Design of a magnetic field assembly to perform the required rectification computation appears feasible. Data processing would be quite rapid and accurate. However, devices, in existence today have sensitive areas in the order of 2-inches in diameter, thus requiring further development to find application here.

C. Scan Converter Type

Flying spot scanning techniques suggests a number of feasible schemes. A typical system is shown schematically in Figure V. A cathode ray tube, with a photograph mounted on its face, can be used to scan in a fixed pattern. A photo tube is used to receive the energy from the light beam which has been coded in intensity by the photo data. These signals to gether with electron beam position data would then be fed through a rectification computer and reconstructed on another CRT tube for recording. The simple device described



FLYING SPOT SCANNER SCHEMATIC

FIG V.

is limited in photographic area that can be scanned as well as resolution. Phosphors limit the latter to 5 to 10 lines per millimeter.

Other variations of this general scheme are possible. Combinations of opto-mechanical, electronic and storage device can be utilized to improve resolution and increase the area of photograph which can be scanned. A point source and a glow modulator tube for reading and writing applications in opto-mechanical systems can be designed to obtain resolutions in the order of 40 lines/mm. The procedure here would be similar to the flying spot scanner technique. The photograph would be scanned in a regular pattern with a high resolution spot. The data stored so as to permit readout and reproduction with rectified sweeps. In small areas storage devices are currently being developed which will permit storage of 40 elements per lineal millimeter. However the gray scale of these units is limited to 4 or 5 tones.

Intercontinental Electronics Corporations radar to television scan converter employs a single tube with a configuration which might be useful here. The INTEC TMA403X video transformation tube embodies in one unit a writing gun, a collector or storage unit and a reading gun. With this unit it is possible to write data at one rate and readout simultaneously at another. As applied to our rectification problem, the photographic data could be written into the storage facility on a one to one basis and read out with sweep scans which have been computed to obtain the desired rectified image. This unit is capable of 16 lines/mm in resolution and a gray scale which would permit presentations of professional television quality; that is, a tone scale of ten to twelve. However, this tube has a storage area of only two inches in diameter. Employment of devices such as the video transformation tube would permit accurate, rapid rectification with flexibility limited only by the complexity of the computer. Large area tubes with better resolution are technologically feasible. However, they are not available today and would require further development to merit consideration for this problem.

Subsection D. Opto-Electromechanical Rectification Systems

A typical opto-electromechanical system which essentially performs a point by point plot is illustrated in Figure VI. In general these schemes include three major components. These are: two scanning systems, one for reading and one for writing; and a computer which correlates the functions of each scanner.

The readout scanner consists of a moveable film platen on which the negative data to be rectified is positioned, a high intensity point light source which is optically imaged on the negative and a photo-electric device which measures the intensity of the light permitted to pass through the negative.

The writing scanner consists of a movable film platen on which the negative to receive the rectified image is positioned and a light source assembly which transmits the photographic video information to the negative. The video signal from the readout unit modulates a light source such as a Sylvania Glow Modulator tube (these tubes are used in facsimile transmission equipment). They are capable of modulation rates in the order of 1 million cycles per second with a reasonable gray scale. The optical system focuses the modulated point source onto the negative material.

The computer receives known position data, performs the required rectification computations and issues position commands for the other scanner. In our case, to simplify exposure control, the writing scanner is designed to plot at a uniform rate. The computer receives position information from the scanning head and movable film platen, and on the basis of a rectification computation, commands are issued to the readout scanning head and film platen. Servo mechanism techniques are employed in the computer to achieve the desired accuracy. The computer can be designed to be extremely flexible permitting use

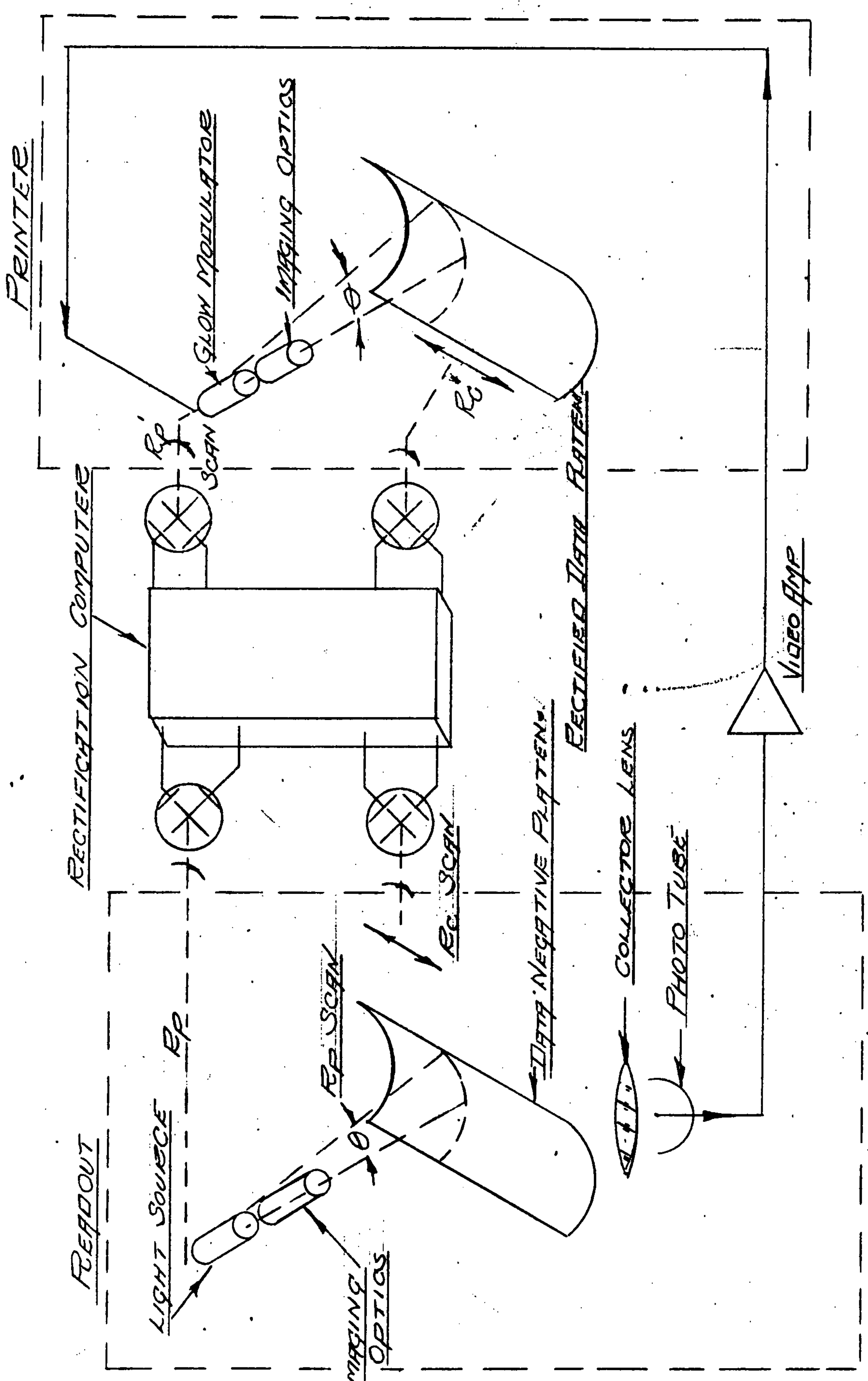


FIG VI

OPTO-ELECTRO-MECHANICAL RECTIFICATION SCHEMATIC with conventional and panoramic photographic data as well as independence from scale factor and taking in lens optics. Additional technical considerations are described in greater detail in the appendix.

The basic system described here lends itself to modifications which would improve operation of the rectifier. For an example, if in place of the phototube video circuitry an optical transfer system was used it would be possible to transform several picture elements simultaneously and thus speed up the operation. It would also be possible on these systems to introduce intensity control circuitry which would enhance details in dark and bright areas of the original photographs.

In summary the opto-electro-mechanical schemes described here are limited in flexibility and versatility only by the process time requirement and computer complexity. The scanning rates are limited by the servo mechanism system to about 10 lines per second. However, system resolution in the order of 40 lines/mm is very easily obtainable with a satisfactory grey scale.

Subsection E. Correction for Earth's Curvature

If desired, correction for earth's curvature can be added to the computer of the schemes described above. However, a unique device can be designed to perform this correction by itself. The design is based onthe fact that the heading to any point from the nadir point on a rectified photograph is accurately shown. The correction is simply a radial factor being a function of the distance from the nadir to that point, earths curvature and altitude of taking camera.

Optical scanning devices have been designed and built which employ wedges to deviate an energy beam. In these schemes two wedges rotate in the same direction about the same optical axes. When the wedges are in phase, the deviation of the beam is at a maximum and equal to the sum of deviation of the two wedges. When the two wedges are opposing, the deviation is equal to the difference or equal to zero for two identical wedges. The energy beam is thus coincident with the optical axis of the system.

If the two wedges are made to rotate in the same direction at a slightly different rate, they can be made to generate a spiral having a pitch equal to one picture element. In our case this would be at the rate of forty lines per millimeter.

The two scanning devices in the system would be very nearly the same. The procedure here would be to have a high intensity point source imaged onto the data negative and deviated in a spiral by two optical wedges rotating in the same direction at slightly different speeds. The light is modulated by the film density and collected by a phototube. After suitable amplification, it would control the intensity of a glow modulator tube. The intensity modulated crater of this tube is then imaged onto a negative. Its position being established by another set of wedges. The two scanners are synchronised. The measured deviation of one scanner would be multiplied by earth's curvature correction factor to obtain the proper deviation for the second scanner.

A spiral scanning device, such as described here, could be very rapid and accurate. However, it is limited to performing only the function of correction of earth's curvature on rectified photographic data. Unless there is a great need for a device such as this, it is more desirable to include this correction, within the computer directly even at the expense of an increase in system complexity.

SECTION 4 - PROPOSED APPROACH

The ideal rectifier must be accurate, capable of rapid data processing, and versatile so as to permit rectification of conventional and panoramic data with broad limits in roll and pitch. The rectification computations which must be performed rapidly are indeed complex, in themselves predicting a difficult design problem. A number of possible designs, which could be used to perform the indicated rectification operations, have been described briefly in the body of this proposal and further detailed in the appendix. Even in the simplest forms these are considerably more complex than optical rectification systems in use today. This is further illustrated by the simple, accurate and compact optical design submitted here for panoramic data rectification.

In view of this it is recommended that the rectification problem be divided into two phases. Since there is an urgent need for an accurate and rapid rectifier for panoramic data obtained with the Perkin-Elmer Model 501 Camera, it is recommended that the optical system described here be constructed to satisfy this need. On a longer term basis it is proposed that Perkin-Elmer be allowed to undertake a design program to arrive at a more universal device performing the rectification problem electronically.

The division of the rectification problem into two phases will permit proper evaluation of all parameters in an electronic rectifier without handicapping the immediate need for rectification of data taken with panoramic type cameras. At this time only a design phase is indicated. Electronic rectification schemes described here as well as others will be evaluated in detail. The technical evaluation will consider flexibility, ease of operation, accuracy, and total processing time. Based on the findings a single system will be selected and recommended. The selected system will be described in detail. Included will be layout drawings, block diagrams, as well as the operational specifications. A report summarizing this effort will then form a proposal to construct and develop a prototype unit.

SECTION 5 - CONCLUSION

The Perkin-Elmer Corporation is well-qualified to perform the required effort in the proposed two-phase program. Its unique optical capabilities and complete technical knowledge in the fields of panoramic cameras and photography assures a successful solution to the immediate need for an optical panoramic data rectifier. Similarly, Perkin-Elmer's experience with opto-electro-mechanical devices, in both the commercial and military fields, predicts the successful execution of the second phase for a practical electronic rectifier design.

APPENDIX

1. Description of Perkin-Elmer Model 501 Panoramic Camera
2. Description of an Optical Panoramic Data Rectifier
3. Description of Resolver Applications in Opto-Electro Mechanical Systems

PERKIN-ELMER MODEL 501 PANORAMIC CAMERA

SECTION I

GENERAL DESCRIPTION

1. PURPOSE AND BASIC PRINCIPLES

The Mark 1A Tracking Camera, a modification of the Mark I Tracking Camera, is a lightweight panoramic camera designed to provide photographs of a 180° field.

The Mark 1A is an automatic sequencing camera which contains sufficient film to provide photographic coverage of a complete mission. It may be set for either adjacent or stereo overlapping pictures. It is a shutter-less scanning camera in which the motion of a continuously rotating glass prism is synchronised with the motion of the film during each cycle. The aperture is controlled by a programmed slit, exposures being made while the film is moving over the slit. For the Mark 1A, scan time is set at 1/2 second. Detailed principles are given in Section II, Theory of Operation.

2. GENERAL PHYSICAL DESCRIPTION

Normal operating controls are mounted on a recessed control panel located in the top of the camera. Extending from the bottom of the camera is a hyper-hemispherical glass dome within which is located the rotating prism.

The camera sprockets, film reels and film guides are mounted on the frame in one compartment and are accessible upon removal of the rear cover.

The cameras' drive mechanisms and electrical assemblies are mounted on the opposite side of the frame in the front compartment. Protruding through sealed openings in this cover is the power input receptacle.

The sealed construction of the camera minimizes the effect of humidity within the camera. Hose connections are provided for pumping and dry gas flushing of the interior of the dome before placing the camera in operation.

A desiccator and breather tube assembly are mounted on the rear cover. It is used to keep the humidity low during pressure equalization while the camera is in use. Also, metal radiation shields are mounted in the dome to localize condensation on the unused portion of the interior surface.

3. TECHNICAL CHARACTERISTICS

GENERAL

Weight .... 40 lbs.

Dimensions .... 37-3/4 x 18-1/2 x 7-1/2 in. above mounting surface. 3-1/2 in. below mounting surface.

Power Required .... 24 - 30 volts dc, 3/4 amp. continuous load with intermittent peak loads to 4-1/2 amp.

Film Capacity .... 1000 ft., 70mm, standard base film, perforated MS33525 on special spools, with leader. Film consumption 10.472 in. per exposure. Threading may be easily accomplished on open-ended sprockets, without feed-through.

OPTICAL

Objective .... 3 in. E.F.L. f/8 fixed focus Orthometar type objective.

Prism .... Wedge compensated double dove prism equipped with masks to provide uniform exposure to horizons.

Mirror .... Front surface reverting mirror, graded coating for uniform field illumination.

Filters .... Aero filters, Red, Minus-blue, Clear.

Dome .... Hyperhemispheric dome, ground and polished.

Resolving Power .... 40 lines/mm minimum.

Format .... Angular coverage $42^{\circ} \times 180^{\circ}$. Picture size 2.375 x 9.425 in.

ELECTRO-MECHANICAL

Exposure Control	Slit width automatically adjustable by means of programmed cam.
Exposure Intervalometer . . .	Self-contained intervalometer providing exposure intervals from 2 seconds to 64 seconds. A manual trip switch is also provided.
Allowed Overlap	In transverse panoramic aerial applications, the intervalometer range can provide for various ratios of altitude/speed, between 11 feet per knot and 360 feet per knot.
Scan Time	1/2, second for 180° scan. Speed-regulating governor. Film metering occurs between scans only.

SPECIAL FEATURES

Camera attitude recorded on each exposure at instant of scanning nadir. Time of completion of each scan recorded on each exposure. Remote signal circuit synchronized with time recorder.

Safety shut-off in event of film breakage or other malfunction. Provision for remote starting and stopping by control of power. Fail-safe control circuit design.

Section II

THEORY OF OPERATION

1. GENERAL SYSTEM OPERATION

Scanning principles of the Mark II Tracking Camera are illustrated in Figure 1. Successive sweeping images of a 180° field are projected through a focal plane slit by a continuously rotating prism, fixed objective lens and diagonal mirror. A glass dome of high optical quality protects the system. The scanning head prism is a double dove assembly with a slight wedge between doves to correct twinning due to the lens power of the dome.

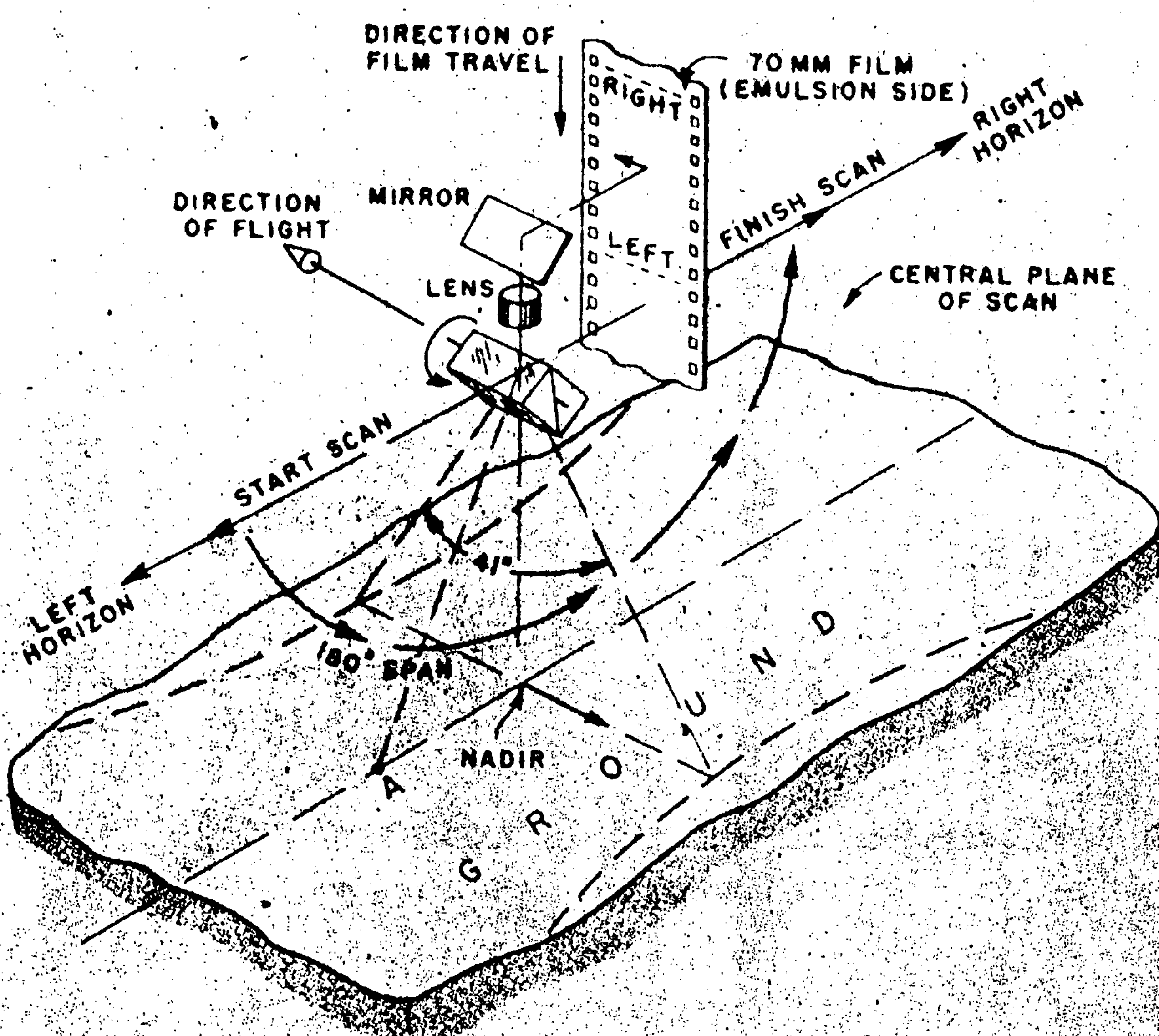
The lens is of a type known as the Orthometar of 3-inch effective focal length, relative aperture f/8. It is color corrected for use with any film and has a flat field and low distortion. Focus is fixed at infinity, taking into consideration the power of the dome.

A diagonal mirror, located close to the image is used to correct the image reverted by the prism. The mirror is coated with a partially absorbing film of varying thickness designed to equalize the illumination over the whole field. A set of three aero filters consisting of Aero Red, Aero Minus-Blue and Clear are included.

Film is transported in synchronism with the image. Two diagonally opposite edges of the prism are masked. These masks cause a gradual reduction of the aperture near the horizons to provide uniform exposure.

Although the film motion is stopped at the end of each 180° scan, the prism rotates continuously. The intermittent film motion is started at selected intervals and at an angle during prism rotation when the line of sight starts the scan. Since the prism can be used in one direction only, the choice of exposure intervals is limited to whole multiples of prism turn intervals. The focal length of the lens is closely controlled to provide exact synchronization of the image and film velocities.

The intervalometer is an electro-mechanical device for generating electrical pulses of a constant time duration and accurate time interval. It is used to establish the interval between exposures.



Figur. 1 - Scanning Direction and Limits

The brightness of the image is controlled by an adjustable focal plane slit. A knowledge of film speed, filter factor and scan time is required to obtain proper exposure. These factors are combined as a sensitivity factor which is established by means of the controls designated APERTURE RANGE-AUTOMATIC and APERTURE RANGE-MANUAL.

The APERTURE RANGE-AUTOMATIC control has a range of exposure factors of 2^5. The position which most closely approximates the calculated value is used during operation. The selection of the correct range is necessary to control the degrees of rotation of the follow-up drive mechanism for a given change in illumination.

Within the selected range, the photocell and transistor circuit provide a current proportional to the overall scene brightness. This current is balanced by the output of the follow-up potentiometer which automatically controls the setting of the aperture for correct exposure.

In APERTURE RANGE-MANUAL operation, the manual control simulates the output of the photocell and transistor circuit.

In aerial survey applications, compensation for image motion is achieved by the harmonic axial displacement of the film transport sprocket and focal plane rollers. The displacement velocity is at a maximum when the line of sight is vertical and varies inversely to the slant altitude during scan.

The image motion compensation mechanism is essentially a lever, a stylus and a circular wedge which is adjustable externally by means of a dial on the front cover. Rotation of the dial sets the displacement amplitude by positioning the stylus on the slant surface of the wedge. When the wedge is rotated it imparts harmonic motion to the lever. The selected displacement is based on values of the speed-altitude ratio and the time of scan.

The format of each exposure is illustrated in Figure II. The image of a bubble superimposed on a reference grid is projected on the moving film by a revolving mirror and fixed lens in the vertical indicator as the scan reaches nadir. Since the grid image has a fixed offset position from the location of the camera nadir axis, a correction can be obtained from the position of the bubble relative to the grid to determine the location of the gravitional nadir on each exposure.

The lens of a time indicator focuses an image of a watch face on the film plane. As each scan is completed and the film is temporarily stationary, the image of the watch face is exposed. Brightness of the exposure lamp is rheostat controlled.

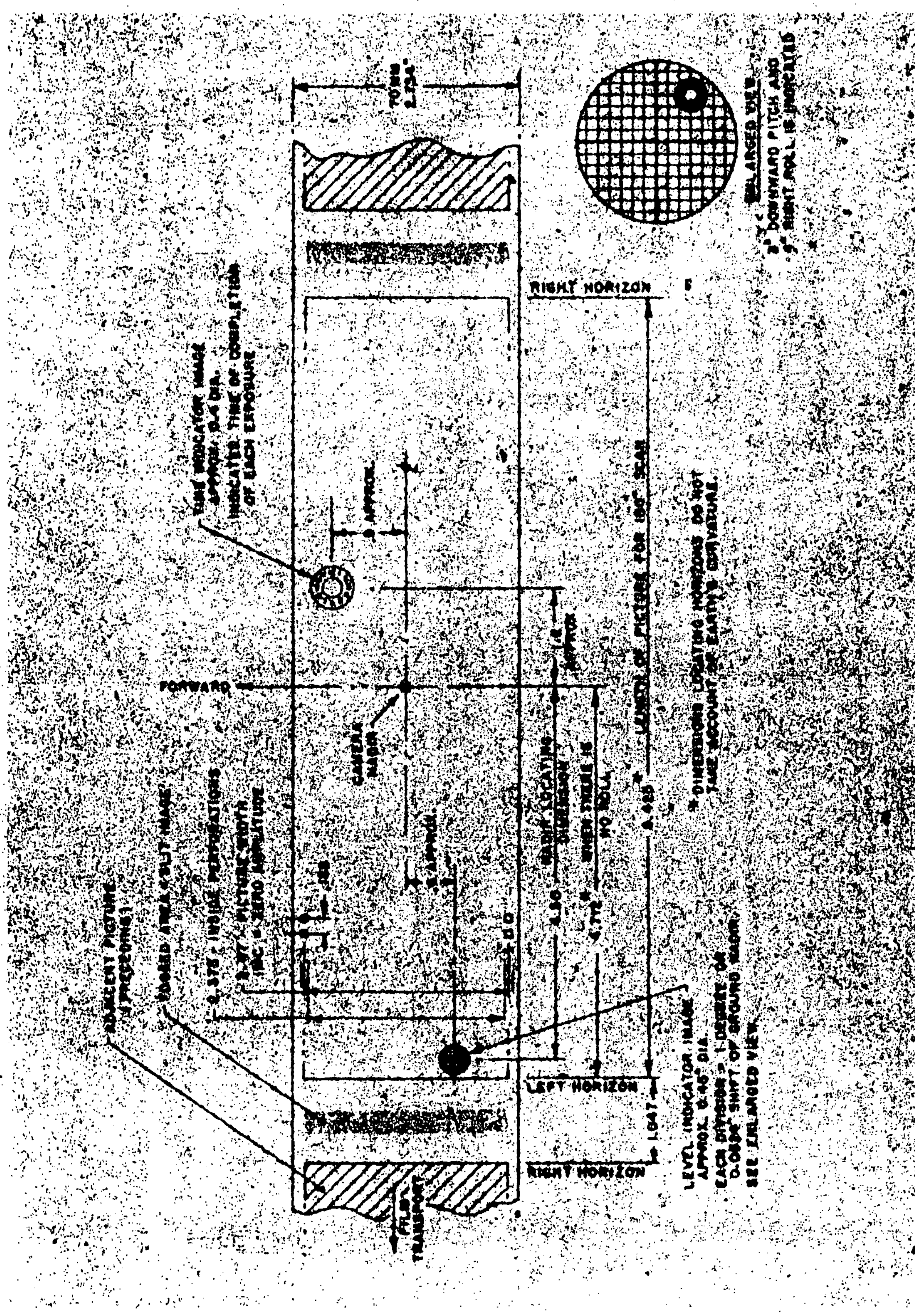


Figure 11. Film Format

OPTICAL, PANORAMIC DATA RECTIFIER

PURPOSE

To rectify in single stage, 60° each side of vertical, 70mm negatives taken with the tracking camera.

TECHNICAL SPECIFICATIONS

Objective focal length - 3" lens used for original negatives.

Rectification - 60° each side of vertical.

Magnification - 1 to 1 at center of picture.

Illumination - Sufficient for focusing and capable of manual control for printing.

Film and spool - 70mm perforated and unperforated film, format 2.47" x 9.425"; wound on standard 10-1/2" diameter flange.

DESCRIPTION

The rectifier is to be designed so that the original negative panoramic film is wound across a cylindrical backing surface which is transparent, thru which condenser illumination is providdd. The remainder of the system consists of a slit thru which the image is focused, the field flattener lens, the taking lens, the special 120° field lens and an iris. The iris is built into the field lens and will range from f/11 to f/16. The 120° field lens shall be mounted in a stationary cell rigidly attached to the print plane and approximately 68mm from it.

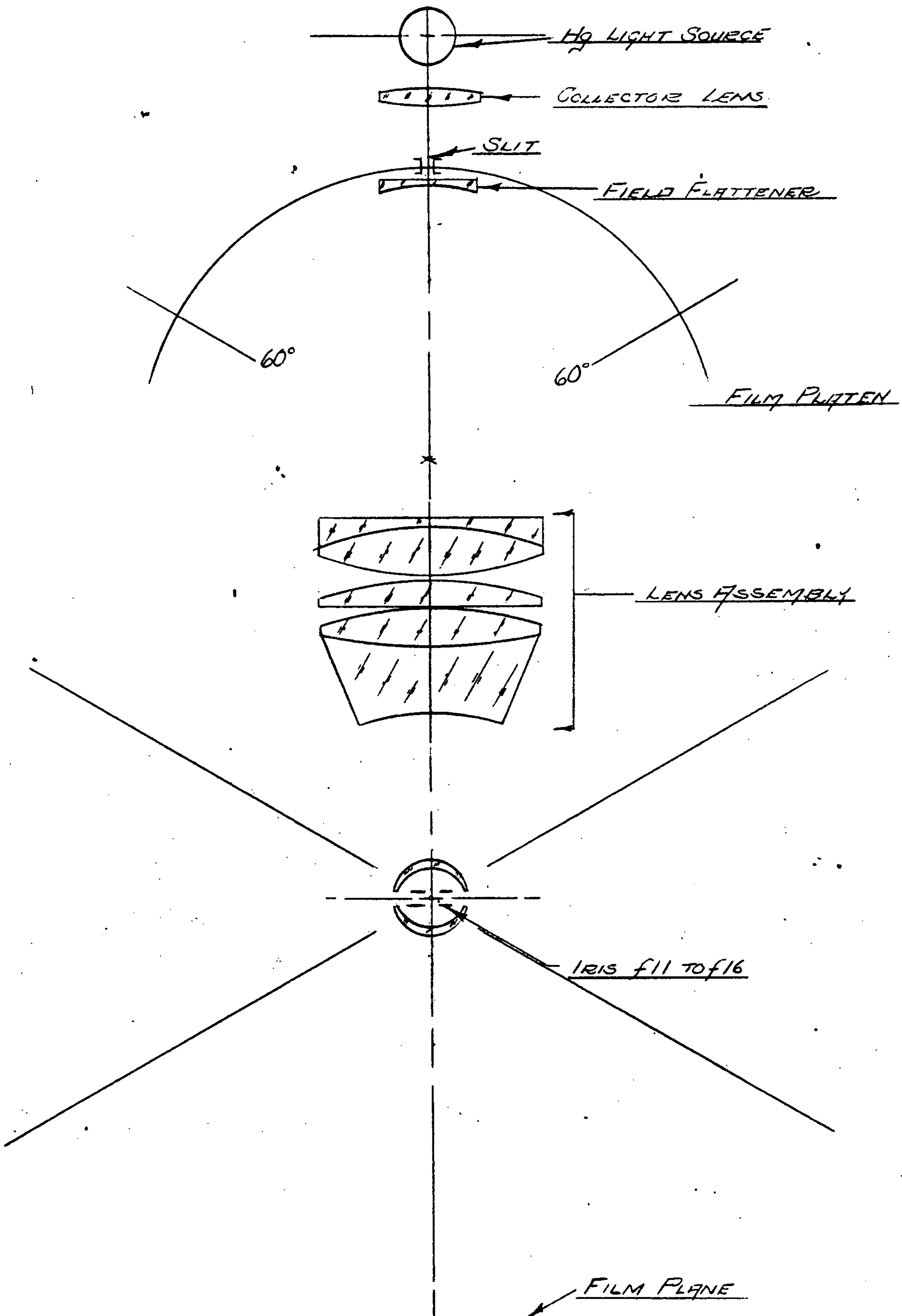
The print plane, and 120° field lens mounted on gimbals for tilt, and adjustable both in roll and pitch. There will be scales for these adjustments. The tilt adjustment is required and is used when panoramic sweep has been taken fore or aft of the vertical transverse plane.

Figure number one shows the optical schematic. The mercury source, the collector lens, the slit, the field flattener, and the taking lens will be mounted in a common cell, pivoted about the geometric center of the 120° field lens. This common cell shall be cast integral with a 150° sector which is mounted on ball bearings and constrained by an upper guiding roller.

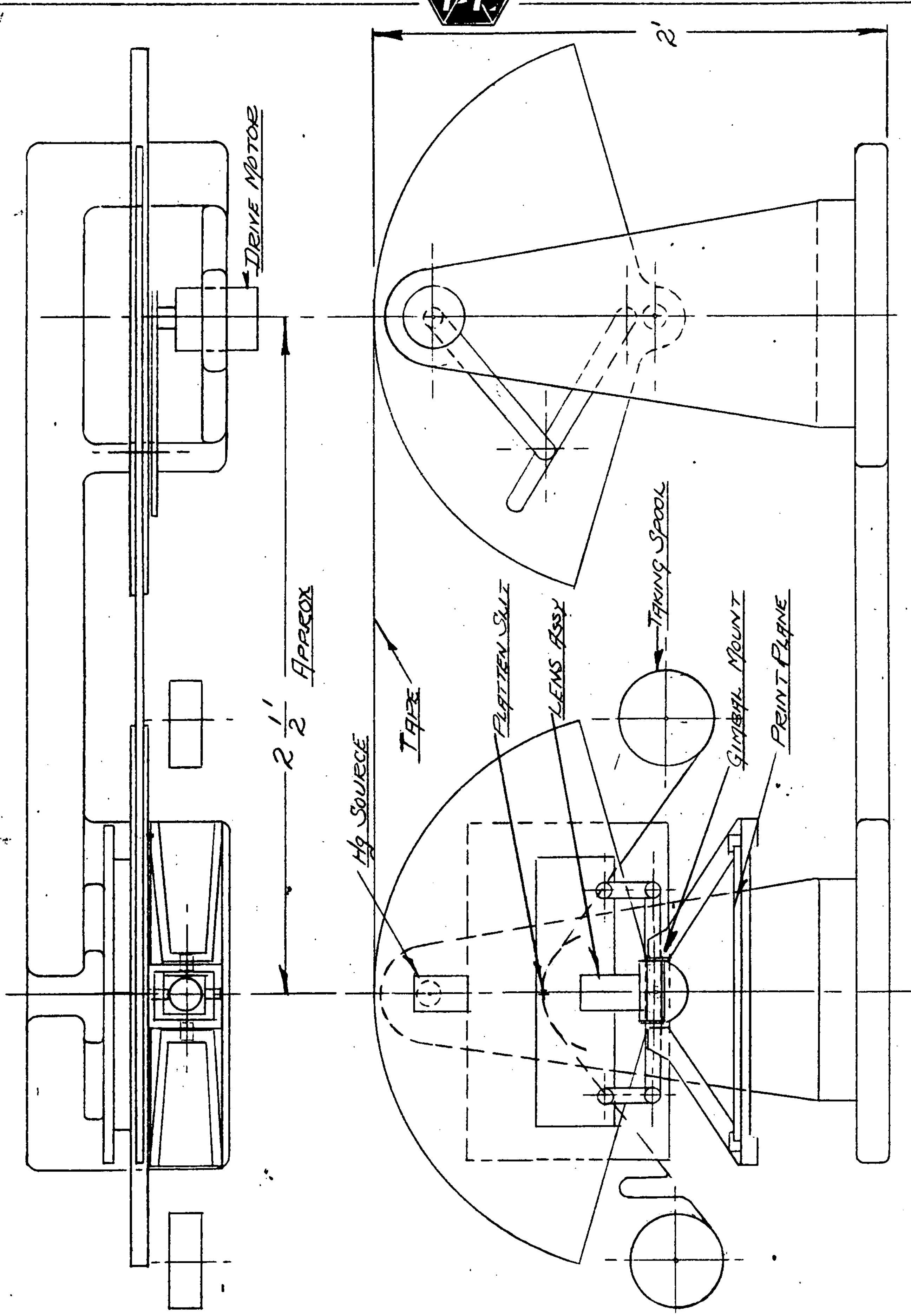
To properly maintain exposure, it is necessary to drive the lens assembly via a cosine fourth motion. This is accomplished by mounting another 150° sector on a stationary bracket, the periphery constituting a cam and having on its face a drive groove. This sector, pivoted in the same manner and on the same plane, is driven by a drive motor directly coupled to the lever and clamped to the stationary bracket. The groove is designed so that the proper velocity is reached before the exposure takes place. Concurrently a tape drive pulls the lens sector thru its cycle.

The film platen, which can accomodate either perforated or unperforated film, is mounted to an adapter which is the cross-arm of a parallelogram, one point of which is attached to the lens sector. The lower pivots of the parallelogram are fastened to structure. As the lens sector goes thru its excursion the film and platen move thru an arc the radius of which is equal to the distance from the center of the 120° field lens to the center of the taking lens. At all times the optical axis is pointed directly at the center of the 120° lens, thru the slit.

The use of a tape drive and a sliding cam eliminates the possibility of any backlash which is inherent in a gear system, thus reducing the possibility of banding. Vibration will be reduced to a minimum by making the base and stationary housing of cast iron and mounting the entire system with optical bench rigidity. See Figures II. and III.



ENGINEERING REPORT NO. 5218 OPTICAL SCHEMATIC FIG I



OPTICAL PANORAMIC DATA RECTIFIER

Fig II

RESOLVER APPLICATIONS IN OPTO-ELECTRO-MECHANICAL SYSTEMS

The process of rectification is a geometric computation which transforms co-ordinates of a point in one system to that of another. A point by point rectification system would employ the use of resolvers to perform the required co-ordinate transformation. In the following section we will briefly describe the geometric relationships in a co-ordinate transformation and the use of resolvers to perform the computation.

COORDINATE TRANSFORMATIONS

When the aircraft pitches and rolls there is no longer a simple relationship between a point on the ground and a position on the film. To illustrate let us go through a series of coordinate transformations. The final transformation will present the position of the point Q on the film after the aircraft has gone through the motions of pitch and roll.

In level flight the components of a point Q would be given by Rc and Rp. The transverse displacement from the nadir being given by Rc and Rp denotes the displacement parallel to the line of flight. For this condition the cross and parallel components are the same for the earth and aircraft co-ordinate system since they are displaced by altitude alone. Under conditions of roll and pitch the two co-ordinate systems are not only displaced by altitude but rotated with respect to each other.

The aircraft axis system is defined by a line thru the fuselage being perpendicular to a line parallel to the wings and a line perpendicular to both the fuselage and wing axis. In this system roll is about the fuselage axis and pitch is about the wing axis.

Figure I illustrates the co-ordinate transformation for pitch alone. The co-ordinates of the point Q are given by

$$R_p' = R_p \cos p - H \sin p$$

$$H' = H \cos p + R_p \sin p$$

Rc remains constant since pitch is a co-ordinate transformation about the wing axis so that components on this axis are not altered.

Figure II illustrates the changes in the coordinates of the Point Q in the Aircraft Coordinates System when the aircraft rolls about the fuselage axis after an initial pitch.

The transformed quantities H'' and R_c' are:

$$H'' = H' \cos r - R_c \sin r = (H \cos p + R_p \sin p) \cos r - R_c \sin r$$

$$R_c' = R_c \cos r + H' \sin r = R_c \cos r + (H \cos p + R_p \sin p) \sin r$$

The R_p' co-ordinate is not altered by this transformation and remains

$$R_p'' = R_p' = R_p \cos p - H \sin p$$

The relationship between the panoramic data components and the ground components is found to be

$$R_{cp}'' = f \, \emptyset = f \tan^{-1} R_c''/H''$$

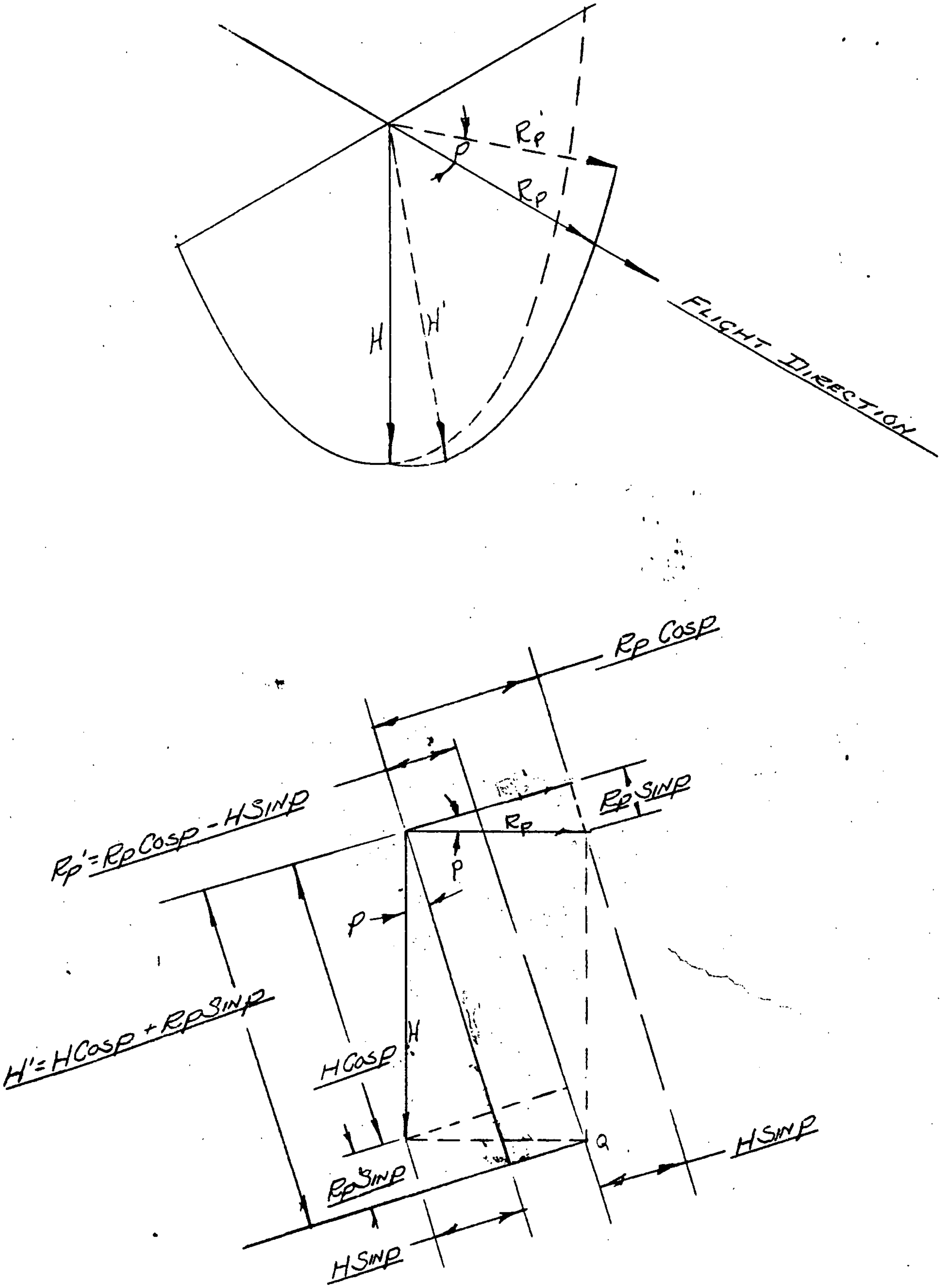
$$R_{pp} = f/H'' \; R_p''$$

Combining these equations yields the computation which must be made by a point by point rectification system. These relationships are

$$R_{cp}'' = f \, \emptyset = f \tan^{-1} R_c'/H''$$

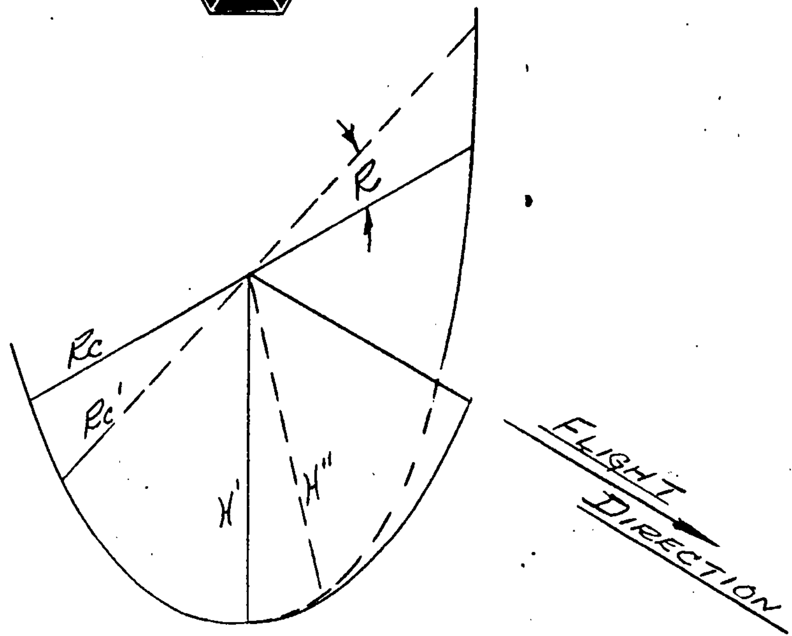
$$R_{cp} = f \tan^{-1} \frac{R_c \cos r + (H \cos p + R_p \sin p) \sin r}{(H \cos p + R_p \sin p) \cos r - R_c \sin r}$$

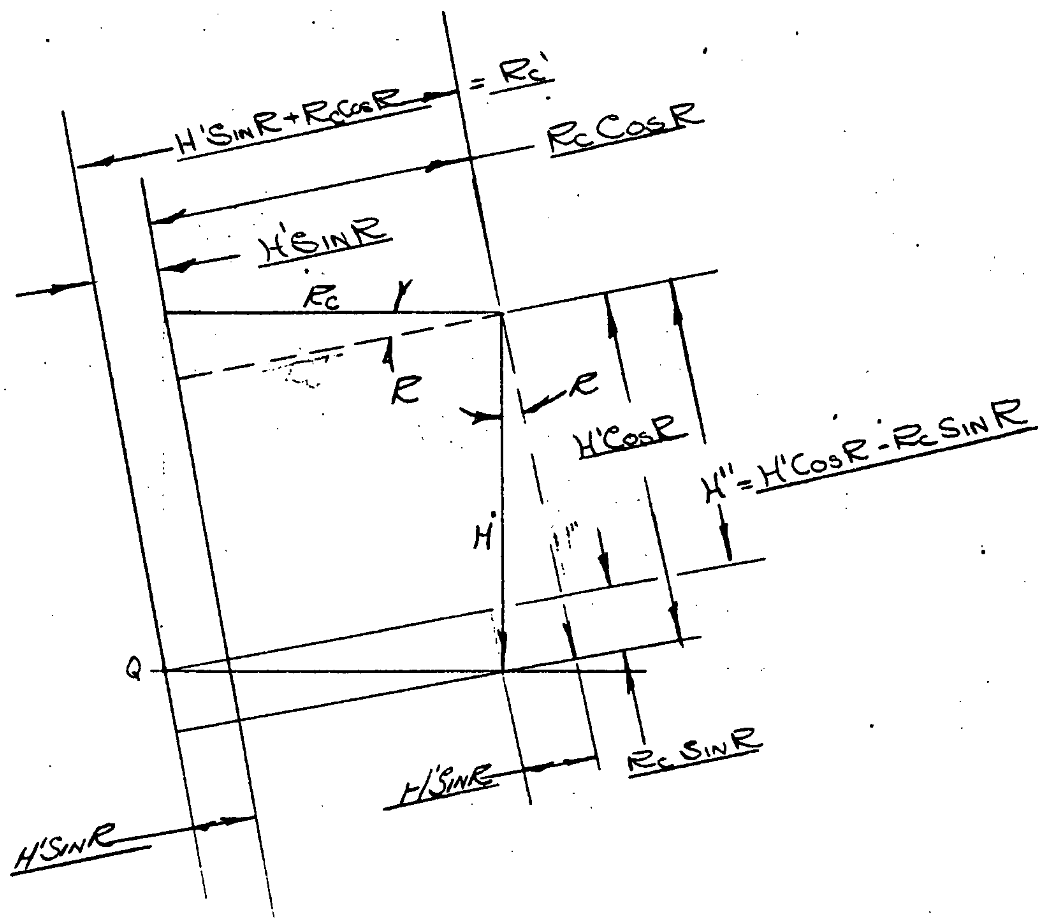
$$R_{pp} = \frac{f \, R_p''}{H''} = \frac{f \, (R_p \cos p - H \sin p)}{(H \cos p + R_p \sin p) \cos r - R_c \sin r}$$



PITCH COORDINATE TRANSFORMATION

FIG I





ROLL COORDINATE TRANSFORMATION

FIG II

RESOLVER SOLUTION TO THE COORDINATE TRANSFORMATION PROBLEM

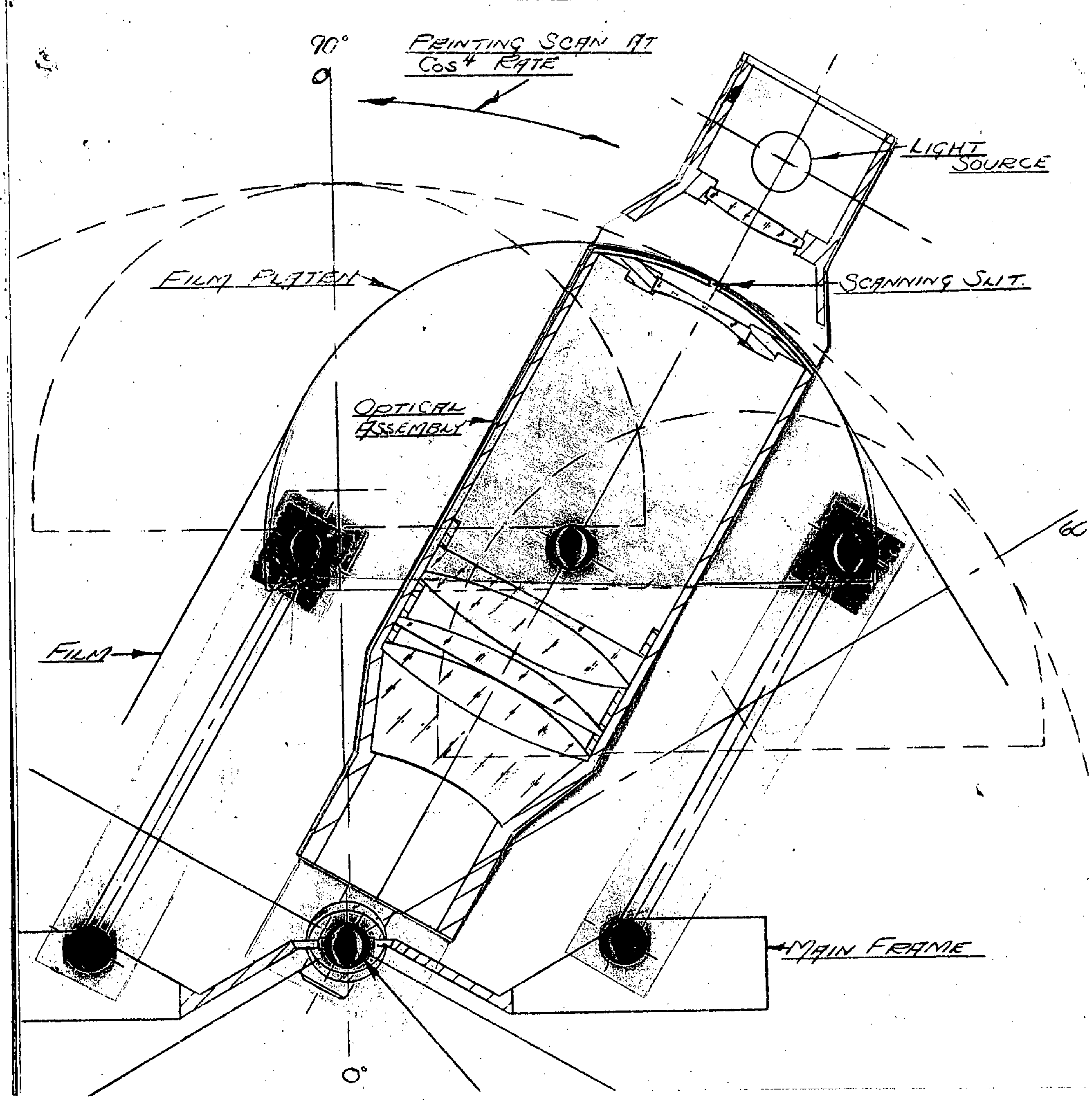
A resolver is an electromagnetic device having two mutually perpendicular stator and rotor windings. A flux vector will result depending on the amplitude and phase of the two input currents. The rotor voltages are proportional to the magnitude of the flux vector and to the sine or cosine of the angle of rotation of the rotor windings with respect to the flux vector. The output voltages may be expressed in terms of the input voltages and rotor angular positions by the following expressions:

$$Eo_1 = E_1 \operatorname{Cos} \theta - E_2 \sin \theta$$

$$Eo_2 = E_2 \operatorname{Cos} \theta + E_1 \sin \theta$$

The expressions for the outputs of the resolver are of the same form as those in the equations derived in the coordinate transformations due to roll and pitch. Resolvers can then be used to perform the indicated geometric computation.

Two curved film holders are arranged to provide movement in the direction R_{cp} and R_c'' respectively. An optical scanning system scans the films in the R_{pp} and R_p'' dimension. The curved film holders provide a constant focal length and a linear relationship between R_p and θ. See Figure VI in text.


90°
PRINTING SCAN AT
COS⁴ RATE
LIGHT
SOURCE
FILM PLATEN
SCANNING SLIT
OPTICAL
ASSEMBLY
60
FILM
MAIN FRAME
0°